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AUTOMATIC VOLTAGE REGULATORS OF THE VEI SYSTEM

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Single System Electronic Voltage Regulators

The first electronic voltage regulator in the USSR was installed in 1939 at one of the Mosenergo stations for regulating the voltage of a 100,000-kilowatt generator. Since then, over 200 regulators of this type have been manufactured and installed on the largest generators.

Operating experience over a number of years has shown that electronic voltage regulators are thoroughly reliable devices with the added advantages of simplicity of manufacture and greater flexibility in their application possibilities. Their main defect, in cases where the station's own requirements are supplied from the generator busbars (the principle method used at modern stations), arises when this supply voltage drops appreciably. Thus, in breakdowns associated with a voltage drop in the network, the voltage on the station busbars will also drop by an amount depending on its ties with the network. This may reduce the ability of the regulator to provide the required forcing in restoring the desired voltage.

In the existing regulator design, this defect is eliminated, first, by choosing the regulator parameters so as to ensure 150-160 percent forcing under normal conditions and, second, by providing a device for mechanical forcing. However, this device was not sufficiently refined, due to the low recovery coefficient given by the existing minimum-voltage relays which usually does not exceed 0.85. Increasing the recovery coefficient in the normal design adversely affects the reliability of the contacts. Therefore, the setting of the minimum-voltage relay cannot in practice exceed 80 percent of the rated voltage. In many cases, when a generator is operating on common busbars or through a small reactance, the voltage on the generator busbars drops very little, even with complete loss of generator excitation; therefore a mechanical forcing arrangement with a setting of 80 percent of rated voltage will not work.

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These defects of the electronic regulator gave rise to some changes in its circuit and construction.

A 4TslM diode is used in the measuring element (as in the case of the old design) for the following reasons:

1. It results in a sharp variation of the output voltage with respect to changes in regulated voltage, thus simplifying the circuit of the other elements of the regulator.

2. Voltage regulation is obtained on the basis of the effective value.

3. The characteristic of the measuring element does not depend on frequency, and is nearly independent of temperature variations.

4. The life of the diode for continuous operation is over 2 years due to the low-filament voltage used.

Type TG-15/2,000 Thyratrons, operating on an average current of 5 amperes, peak current 15 amperes, and inverse voltage 2,000 volts, are used in the power element of the regulator. With such Thyratrons, the regulator can give an output of 350 volts at 10 amperes continuous operation. Up to 15 amperes forced overloading can be maintained for not more than 2 minutes. In the new regulator circuit, a specially designed electronic minimum-voltage relay, operating reliably with a recovery coefficient of 0.98-0.99 /3/ is used instead of the normal minimum-voltage relay. Inasmuch as the relay setting is determined by the measuring element of the regulator itself, it can be made very near the nominal voltage (0.95-0.97). Thus the effectiveness of mechanical forcing will increase considerably.

A second alteration in the regulator circuit is the introduction of current compounding. (The introduction of components from the current transformers into the supply circuit for the plate transformer was suggested by I. A. Syromyatnikov in 1944). A special plate-transformer design is used in the regulator circuit. It consists of a four-section core which has, in addition to the normal primary winding fed from the voltage transformer of the generator or from the station busbars, a supplementary winding fed from the current transformer. The compound operation of the generator is ensured by a suitable selection of the phases of the regulator supply voltage and current. In case of a short circuit in the system, the decrease of plate voltage on the Thyratrons, caused by the voltage drop on the station busbars, is to some extent compensated for by the rise in plate voltage due to the increase in load current. With compounding, the transformer design provides for the possibility of supplying the primary voltage coil either from a voltage transformer at the generator terminals or from the station supply. In the latter case the compound winding should be short-circuited.

In the new voltage regulator design the method of stabilization has been changed. The elimination of self-sustained oscillations is accomplished mainly by introducing R-C circuits into the measuring element. Only a small part of the exciter voltage is applied through the potentiometer in order to obtain the optimum form of the transient process.

In the old regulator design, the full exciter voltage was applied to the flexible feedback circuit. This usually caused a considerable drop in the rate of increase of exciter voltage. A variable resistor is provided in the diode filament circuit which permits changing the balance voltage of the measuring bridge during tube replacement and for other necessary reasons. A selenium rectifier is used instead of a kenotron in the measuring element.

Double System Electronic Voltage Regulators

In addition to the single system electronic regulators described above, the All-Union Electrical Engineering Institute (VEI) has also designed and installed at some electric power stations the so-called double system electronic voltage regulators. Double system electronic voltage regulators are used for regulating the voltage of large turbogenerators and hydrogenerators whose exciters have a special auxiliary excitation winding for connecting the regulator. The parts used are similar to those of the previously described regulator. In this case, the output from the measuring element is applied to a double amplifier circuit which controls two Thyratrons in the power circuit. When balance is achieved both Thyratrons stop conducting due to negative bias supplied by a special selenium rectifier. Thus, the direction of current in the auxiliary coil of the exciter is controlled by the Thyratron circuits.

Each Thyratron circuit contains a balancing relay which controls a servomotor shunt rheostat in the excitation circuit of the main exciter. The relay operates on a differential current from the two Thyratron circuits.

The regulator is also provided with a high-speed excitation and de-excitation device which operates on maximum- and minimum-voltage relays of normal design.

In normal operation on a large hydrogenerator, the regulator is capable of varying the generator excitation by plus or minus 40-50 percent of rated value.

Electronic Voltage Regulators for High-Frequency Generators

Recently, high-frequency generators have come into use for supplying a number of installations. The operating conditions of these generators require the maintenance of voltage within plus or minus one percent with sufficiently high-speed regulator action. Carbon-pile voltage regulators cannot always satisfy these requirements. For this reason, the All-Union Electrical Engineering Institute has designed and manufactured a group of regulators for small-power high-frequency (800 cycles) generators /4/.

The circuit is almost the same as that used for the single system electronic voltage regulator described above. Two TG-213 type Thyratrons are used in the power element of the regulator, connected in an ordinary full-wave rectifier circuit. The use of type TG-213 Thyratrons in AC circuits with a frequency of 800-1,000 cycles is quite permissible. The maximum value of the rectified voltage at the regulator output is 135 volts at one ampere; the voltage is maintained at plus or minus 0.5 percent of set value. A special stabilizing device is provided for eliminating self-sustained oscillations which, at the same time, ensures great speed of voltage restoration /5/. When the generator load is altered from no load to nominal load, the transitional process is accomplished in less than 0.1 second. The dimensions of the regulator are 200 x 180 x 160 millimeters and its weight is 5.5 kilograms.

A similar type of regulator, using a saturated coil instead of Thyratrons, has also been designed. In this case it was possible to eliminate the auxiliary excitation supply source by means of a special relay circuit for self-exciting the generator.

Voltage Regulators Using a Saturated Reactor for AC Generators of Normal Frequency

The All-Union Electrical Engineering Institute has designed voltage regulators for AC generators, using saturated reactors. One of the regulators was intended for an SGS-4.5 generator (three-phase, 4.5 kilovolt-amperes, 230 volts) but it can easily be adapted to other types of generators. The regulator utilizes the principle of compounding with voltage correction. The excitation winding is supplied by: (1) the exciter; (2) the compounding circuit; (3) the correction

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circuit. The operating conditions are so chosen that, with the generator at rated load, the exciter component is 20 percent, the compounding circuit component is 40 percent and the component from the voltage correction circuit is 40 percent. However, the current ratios can be altered as required by conditions.

It is obvious that a voltage regulator for more powerful generators, in particular turbogenerators, can be constructed on a similar principle. For this it is advisable to dispense with the compounding system and retain only the corrective component. For large turbogenerators, the magnitude of the corrector component in the excitation current must usually be small and therefore the corrector will be comparatively small in size. This scheme has definite advantages over the well-known corrector circuits working on the vibration principle /6/ or with electronic tubes as the power element /7/.

Voltage Regulators With Electric Machine Amplifiers

The widespread use of electric machine amplifiers in various schemes of automatization and electric drive has resulted in their being used also for voltage regulation of large AC generators. In such cases, it is advisable to insert the amplifier armature into the excitation circuit of the exciter. This scheme is especially suitable for generators working on long lines, and for synchronous compensators inasmuch as a very small excitation current can be used and its direction can be altered. An induction motor, fed from the station network, is used to drive the machine amplifier. The drive motor must satisfy a number of special requirements. It must have a large reserve of torque which will be able, (under postbreakdown conditions when line voltage is low) to supply sufficient power to the amplifier as required by the forcing conditions of generator excitation. Moreover, a suitable flywheel must be mounted on the drive motor shaft so that, in case of a breakdown in the system (before the damaged section is cut out) the torque of the motor may remain unaltered (so far as this is possible) during the short time interval in which there may be a sharp drop in voltage across the motor.

A circuit with linear and nonlinear resistances, similar to that used for a saturated reactor regulator, can be used for the control system of an electric machine amplifier. It is also possible to use circuits with electronic tubes. In one version, a 4Ts1M diode with regulated filament supply is used as the measuring element, as was the case in the regulators described above. The circuit also uses a twin triode tube (6N8M), one half of which acts as a cathode follower, while the other half is a normal amplifier with one of the control windings of the machine amplifier in its plate circuit. The magnitude of the current through a second control winding is regulated by a resistor. The magnetomotive forces created by these two windings oppose each other in the machine amplifier magnetic circuit.

When the voltage of the generator increases, the tube circuits cause a rise in current through the control winding in the 6N8M plate circuit. This results in a net decrease of magnetomotive force created by the two windings in opposition and, consequently, the generator voltage drops. An R-C circuit is supplied from the exciter voltage and forms a flexible feedback to eliminate self-oscillations.

The use of electric machine amplifiers for voltage regulation has the following advantages:

1. The small time constant of the amplifier makes it relatively easy to obtain a large system amplification factor. This results in very accurate voltage regulation and fairly rapid attenuation of the transitional process.

2. It is possible to ensure a considerable degree of forcing and hence rapid restoration of generator voltage after a breakdown.

3. The measuring element is of simple construction and its low power consumption from the regulated voltage supply readily permits the use of small-dimensioned direct-sequence filters and compensators.

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